Institutions and ICT Technology Adoption

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Abstract: This paper evaluates the global diffusion process for three ICT technologies: cellular telephony, Internet and personal computers to test the hypothesis that the difference between countries in institutional characteristics significantly affects the time to adoption of these technologies. The analysis shows that the quality of economic and financial institutions and, to a smaller degree political institutions, significantly affects the time to adoption of the studied ICT technologies. The institutional effects were not uniform during all stages of adoption and for all three technologies but the level effects were on average found to be of the same magnitude as those of education and GDP per capita. The results are robust also when controlled for a number of other possible determinants of productivity and growth as well as fixed country effects.

Keywords: Barriers to technology adoption, Institutions, Technology diffusion.

JEL Classification: O33

1. Introduction

The introduction and diffusion of information and communication technology (ICT) infrastructure is often viewed as both an indication and a vehicle of economic success. Access to these technologies in a form suitable to the specific needs of a country is a prerequisite for participation in the global information society. It has also been argued that ICT promote economic growth[1]. But ICT is introduced at very different rates. In some countries mobile phones, Internet access, personal computers etc. were introduced more than two decades ago and have now a penetration between fifty and close to a hundred percent. In other countries they are even today available to a small elite only. A large share of these differences is explained by the level of economic development, but even across countries that are equally rich a number of other factors, institutional and organizational, must influence the time of introduction of ICT infrastructure in a country.

This paper analyses the global diffusion process for three ICT technologies: cellular telephony, Internet and personal computers. The aim is to test the hypothesis that, in addition to differences in economical and educational attainments, there are specific institutional characteristics of countries that significantly affect the time lag until adoption of these technologies, thus adding to a technological divide.

The detrimental effects of low quality institutions on the economic performance of countries have attracted the attention of a number of researchers[2]. The focus has mainly been on three aspects of institutions, economic, financial and political institutions where economic institutions affect incentives, financial institutions affect access to capital and political institutions affect how many will benefit from the rules of the game. The assumption made in this paper is that lower incentives and financing for investment in new technology caused by bad economic and financial institutions as well as barriers and risks caused by restraining political institutions are some of the main causes of delays in investments. This has a more general interest since the level of productivity in a country is to a large extent decided by the level of technology used in production so if bad institutions cause a delay in the adoption of

[1] See for example Onliner and Sichel (2000) and Jorgenson and Stiroh (2000). Even Solow has somewhat renounced his famous quote on the lack of impact of computers on productivity, Uchitel (2000).
[2] For example Acemoglu et al. (2001),(2004), Rodrik et al. (2002), Mauro (1995), Easterly and Levine. (2003), Dollar and Kraay. (2003), Levine et al. (1999), Rajan and Zingales (1998), Claessens and Laeven (2003), Przeworski and Limongi (1993, Persson (2005), Giavazzi and Tabellini (2004), Papaioannou and Siourounis (2004), Tavares and Wacziarg (2000)

new productive technology, the aggregate result over time would be lower productivity. Since the level of productivity is one of the main determinants of growth[3] in a country this would also mean lower growth[4].

To test the hypothesis of a causal relation between quality of institutions and time to adoption of the ICT technologies, proxies for the quality of economic, financial and political institutions are regressed on time to adoption of the three ICT technologies cellular telephony, Internet and personal computers. The corruption index from Transparency International and the IRIS3 composite index of property rights from International Country Risk Guide are used as proxies for quality of economic institutions. Private credit is used as proxy for financial institutions and the polity2 index from the Polity IV project is used as an index of the quality of political institutions.

In this type of regressions one can suspect omitted variable bias. It is possible that factors not included in the regression cause both good institutions and quick adoption of new technology. To address this concern I use two different methods. First, since it is likely that a variable affecting both institutions and technology adoption should also affect growth significantly, obvious candidates for omitted variables in this regression are variables that have been found important for growth. Thus the variables found most important for growth in a number of earlier influential growth studies (Barro 1991, Barro 1996, Sala-i-Martin et al. 2000) are included in the regression to control for their impact. Second I control for country fixed effects.

There is also the case of reverse causation. In growth regressions the problem is usually that one would expect countries with good institutions to have a higher level of economic income. On the other hand one should also expect that more developed countries should be able to afford better institutions. However it is not plausible that one single ICT technology should deeply impact the quality of institutions in a country. Also the use of data for quality of institutions from before the adoption of the new technology addresses this concern.

The findings in this paper are that the quality of institutions significantly affects the time lag to adoption of the studied ICT technologies. The level effect is comparable to that of

[3] Hall and Jones (1998), see also Easterly and Levine (2001) for a further discussion and a number of references.
[4] Of course a test on three technologies can do no more than indicate the relevance of this link.

education and GDP per capita and the results are robust when controlling for a number of other possible determinants of productivity and growth suggested in the growth literature as well as for country fixed effects. However the institutional effect is not uniform neither in all stages of adoption nor during all stages of the lifecycle of the technology. Economic institutions have the greatest impact in the stage when an ICT technology changes from being used only by a small segment of early users to becoming a more mainstream technology used by a broader segment of the population[5]. Financial institutions on the other hand matter most during the initial introduction of the technology in a country. Once a technology has acquired a user base external financing does not seem to be as important. Also financial institutions are most important for countries with an already low level of available credit while there are very small effects in countries where the quality of financial institutions has passed above a certain level. Except in the case of Internet adoption, political institutions play only a minor role and only in the initial stages of adoption (once the impact of economic and financial institutions as well as education and income are controlled for). In the case of Internet one suspects that the information sharing nature of this technology makes it special. As the technologies mature the probability of a country adopting the ICT technologies increases regardless of the quality of institutions (or income and education) so that finally almost all countries have adopted the technologies at some level.

Not only time to adoption is important for the availability of ICT technology but also the rate of adoption once the technology is introduced in a country. The results here show that the single most important factor in explaining the adoption rate is the time to adoption. The later a country starts the adoption process, the higher is the initial adoption rate, enabling late comers to make up for lost time by embracing the new technology faster.

The nature and effect of barriers to technology adoption has been discussed in a number of papers. Parente and Prescott (1994) [6] introduce a model where country specific costs for entrepreneurs contemplating investing in new technology form barriers to technology adoption which delays the investment. These barriers are assumed to take the form of "regulatory and legal constraints, bribes that must be paid, violence or threat of violence, outright sabotage, and worker strikes". They then use the model to explain a number of "growth-miracles". This paper adopts the underlying idea about barriers to technology

[5] Popularly called "crossing the chasm" in the management literature.
[6] See also Caselli and Coleman II (2004)

adoption causing delays in the introduction of new technology and explicitly tests the hypothesis that the barriers to a large extent are determined by the quality of institutions in a country. In the Parente and Prescott model the barriers diminish with the distance of the technology to the technology frontier. This is consistent with the empirical findings in this paper. Other determinants of barriers to technology adoption have been discussed. Parente and Prescott (1999) presents a model where monopoly rights increases barriers to technology adoption. Comin and Hobijn (2005) finds empirical support for a similar model where the lobbying interests of the monopolists work through different institutions. Comin and Hobijn (2003) also finds empirical support for the idea that the speed of technology adoption is affected by income, openness and human capital. They do not test the effect of quality of institutions, except for effective legislative power, since no measure of institutional quality is available for the time period chosen. Glaeser et al (2004) stresses the role of human and social capital as the important factors shaping both institutions and economic outcome in a country. Ciccone and Papaioannou (2005) find that human capital affects a country's ability to adopt new technology. The effects of institutions presented here are robust when controlling for different measures of education.

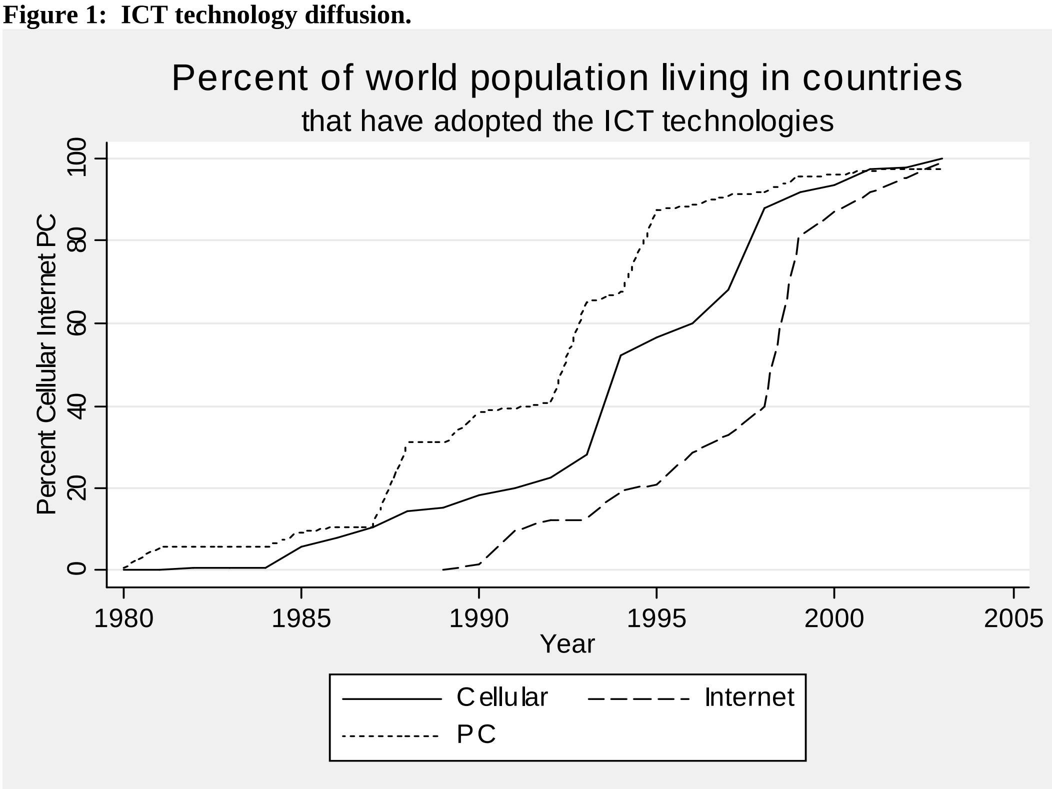
The remainder of this paper is organized as follows: Section 2 presents the data, section 3 discusses the methods used, section 4 presents the results, section 5 addresses the concern of omitted variables, endogeneity and different robustness issues. Finally in section 6 some concluding remarks are given.

2. Data

2.1 ICT adoption

The ICT technologies examined are the three I consider currently most important namely cellular telephony, Internet and personal computers respectively. The dataset used is data from the International Telecommunication Union (ITU) which measures the number of users in the population for each technology since 1980 for approximately 200 countries. For these ICT technologies (and for a large number of other successful major technologies) it has not been a question of adopting or not adopting the new technology. The question has rather been when the technology would be adopted and at what rate. *Figure 1* plots how the three ICT technologies have spread over the world. All three technologies have spread to almost every country on the globe during less than twenty-five years (in the case of Internet it took barely fifteen years for the technology to reach almost all countries on earth). But the diffusion rate has been very uneven. In Finland 0.1% of the population had a mobile subscription by 1980 while it took fourteen more years for China and eighteen for India to reach this level. Bhutan, Afghanistan and Ethiopia reached the same penetration rate first by the year 2003. The dependent variable, $Lag_{ICT} \quad ICT \in \{Cellular, Internet, PC\}$, measures the delay for each country as the time to adoption for each of the ICT technologies. It is calculated as the number of years from the availability of the technology until the number of users in the population exceeds a certain threshold. The time of availability for a particular technology is calculated as $\min(YearOfAdoption_{ICT})$, the first year the number of users in any country in the data exceeds the threshold. The higher the threshold the higher the percentage of users needed for the technology to be counted as adopted and the later this number of users will be attained. Since the level chosen for the threshold will affect the values of Lag_{ICT}, the threshold level will be varied from 0.1% to 20% to test the sensitivity of the results to this choice.

Figure 1: ICT technology diffusion.



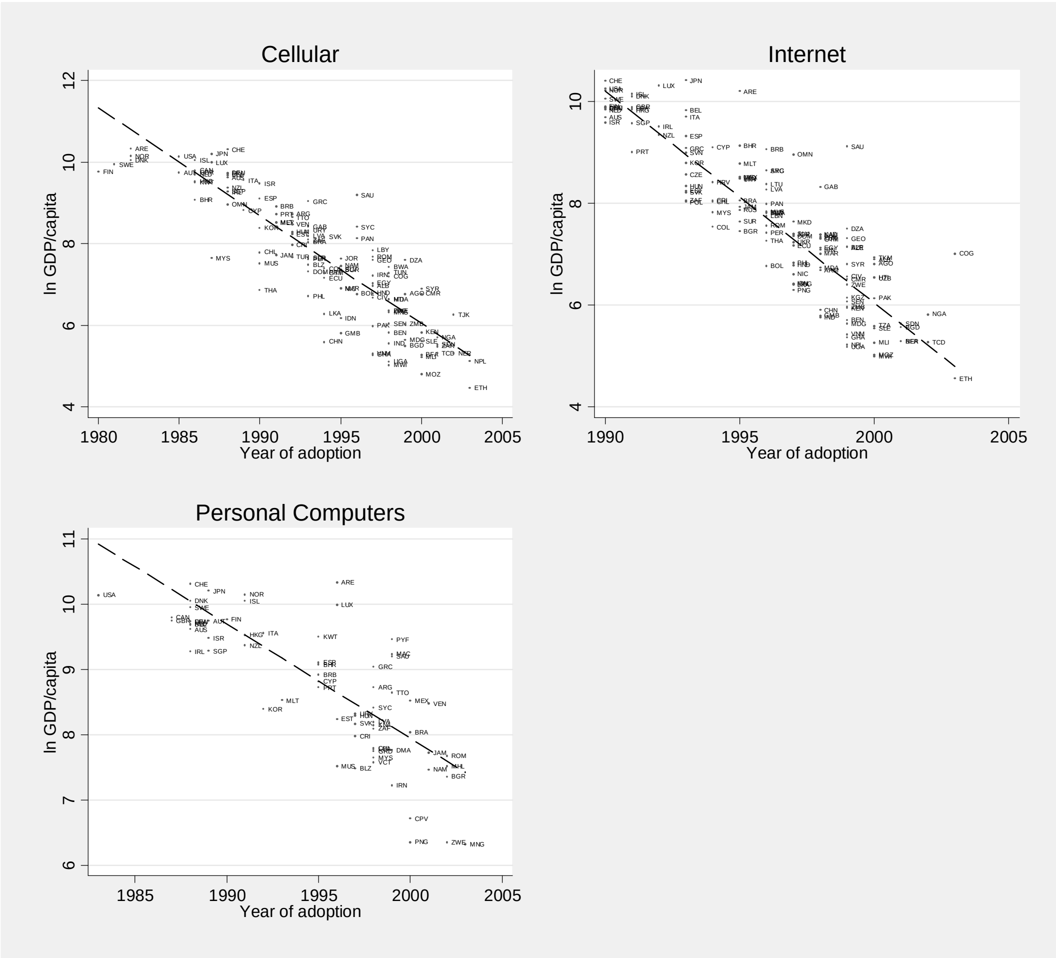
Source: *Authors calculations' using population data from WDI and ICT adoption rate from ITU.*
Note: *Year of adoption calculated as the first year > 0.1% of the population in a country are users.*

2.2 Quality of institutions

ICT adoption is, not surprisingly, correlated with GDP per capita as this affects the ability of agents and firms to pay for the new technology. This is shown clearly in *Figure 2*, which plots

GDP per capita versus time to adoption for a number of countries. However the dispersion is large: countries at similar stages of development vary widely in their time of adoption. For example Malaysia reached a penetration rate of 0.1% mobile users in 1987 while Algeria, with a similar GDP per capita in 1987, had to wait until 1999 to reach the same penetration rate. Other examples are Thailand, 1990, versus Syria and Cameroon (2000). In the case of Internet Portugal reached a penetration rate of 0.1% in 1991 while Saudi Arabia with a comparable GDP per capita in 1990 did not reach this penetration level until 1999. Bolivia (1996) versus Republic of Congo (2003) is another example.

Figure 2. Correlation GDP/capita - time to adoption of ICT technologies.



***Note**: Year of adoption calculated as the first year > 0.1% of the population has adopted the technology. For PC the threshold is > 5% of the population due to missing data for many countries below that level.*

The hypothesis that I intend to test in this paper is that quality of institutions explains part of this variation but a test of this hypothesis requires measurements of the quality of institutions. The effect of economic, financial and political institutions on different aspects of a countries development has been extensively studied in the literature and a number of proxies for the quality of these institutions have been developed. I here make use of some of those.

2.3 Economic institutions

Economic theory suggests that economic institutions affect investment incentives. If on the one hand an agent investing in physical capital, education or improved technology expects to receive a large share of the profit from that investment, market forces will promote investments and these investments will lead to high growth. If, on the other hand, government interventions in the form of expropriation, corruption, distortionary taxes or other fees reduce profitability, both investments and growth will be low.

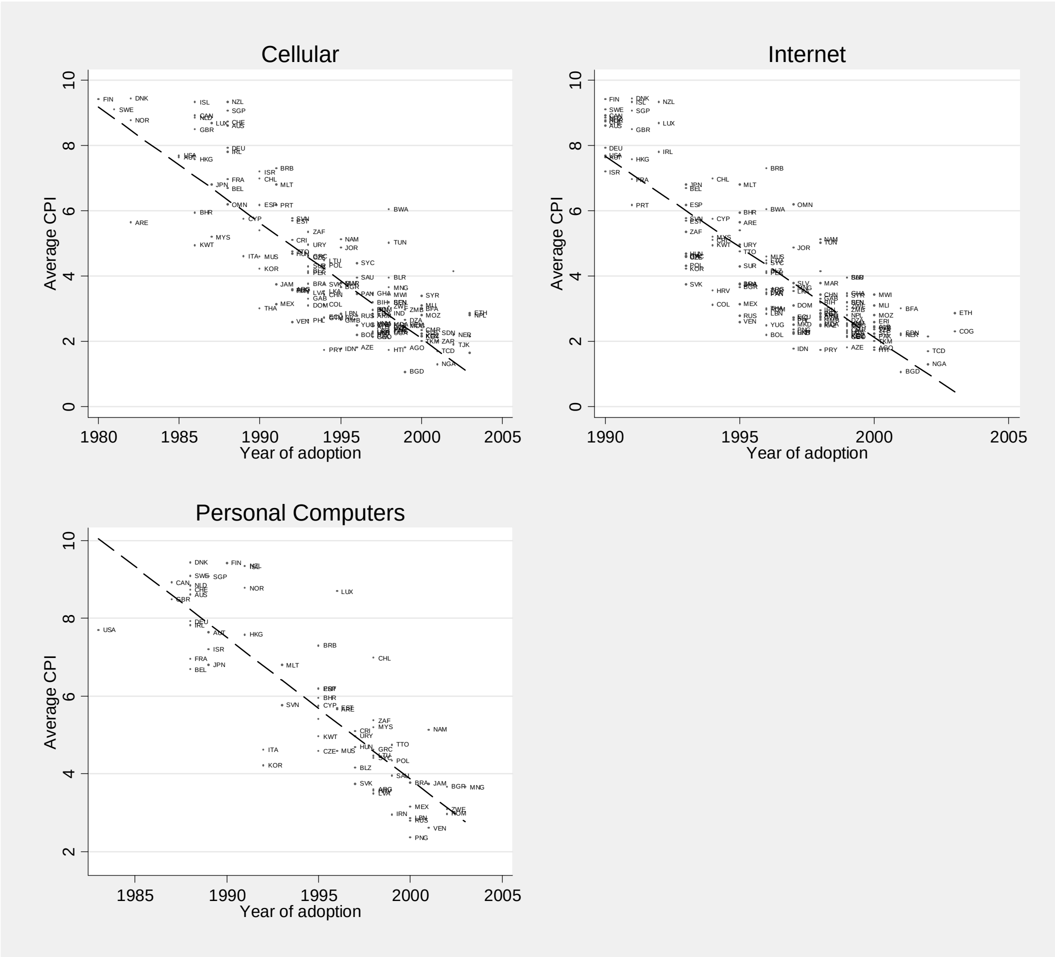
To measure the quality of economic institutions I use two indexes that measure a country's attractiveness for investments based on the quality of its economic institutions. One is a composite index for Government Anti-Diversion Policies (GADP) from International Country Risk Guide[7]. It is based on a number of sub indexes compiled by a commercial firm targeting international investors and made available for academic use in a reduced form by Knack and Keefer[8]. The other is a Corruption Perception Index (CPI) from Transparency International[9]. CPI is calculated as a composite index from a number of sub indexes. About half of these (2004 version) are based on the views of government officials and half on those of business leaders on the impact of corruption. Parts of the questionnaires to business leaders focus on the effect of corruption on the profitability of business both as regards business for domestic as well as foreign entrepreneurs and investors[10].

The GADP and CPI indexes are highly correlated (0.89) and I use them in a complementary fashion. By being compiled over time by just one firm in a hopefully consistent process, GADP is suitable for a fixed effects regression using the within variation. Since it is available only up to 1997 when many countries had not yet adopted any of the ICT technologies at any significant level it is not suitable for looking at the effect of institutions on different adoption levels. As soon as the breakpoint for adoption is set to more than a couple of percent, the level of censoring at 1998 becomes so high that one has to make a lot of assumptions on the distribution of adoption times to get significant results. ICT on the other hand, being created as the sum of a number of sub indexes where number as well as sources of sub indexes used varies over time and the final index is smoothed using lagged values, is not very suitable for

[7] This index has been used as a proxy for institutional development by, among others, Hall & Jones (1998), Acemoglu et al. (2001), Persson (2004)
[8] See Appendix or Knack and Keefer (1995) for some discussions on the index.
[9] This index has been used as a proxy for corruption by, among others, Persson & Tabelling (2003), Treisman (2000) , Wei (1997)
[10] See Lambsdorff (2004) for details.

studying the within variation. On the other hand it is available up to 2004 for a large set (146) of countries and is thus used when studying the effect of economic institutions at different levels of adoption since there is less right censoring.

Figure 3. Correlation CPI - time to adoption of ICT technologies.



***Note**: Year of adoption calculated as the first year > 0.1% of the population has adopted the technology. For PC the threshold is > 5% of the population due to missing data for many countries below that level. AverageCPI is the average over available CPI data for the years 1980-2003. CPI index constructed so that a higher index represents better quality institutions.*

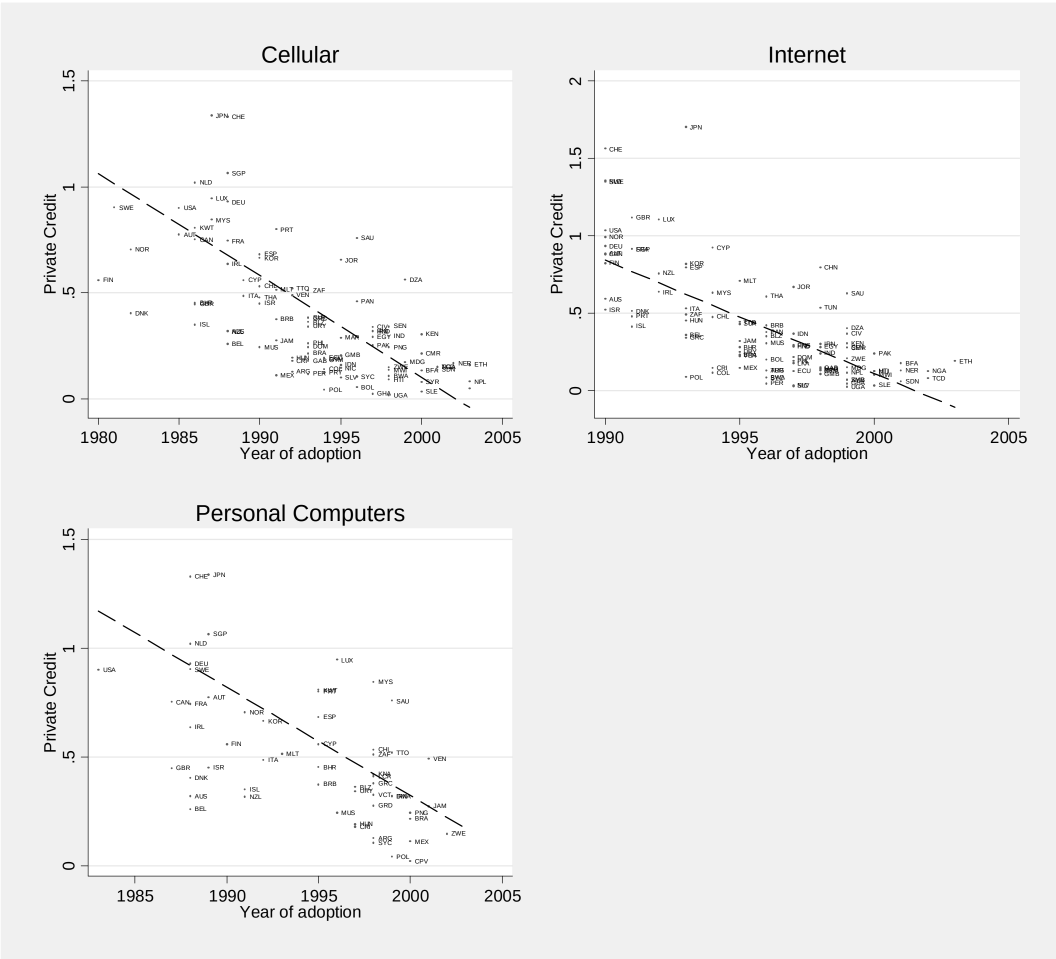
For cross-country regressions the average of the values available for the total time span studied (1980-2003) is used for each index (CPI average and GADP average). The average is used to increase the number of observations because data is not available for a number of countries during some of the first years of the period. Since institutions are considered to be very persistent over time the advantage of many observations outweighs the disadvantage of the increased risk of measurement errors. Both indexes give comparable results in the basic regression[11] but since CPI in my view more directly focuses on measuring the direct effects of economic institutions, only the results for CPI are shown. GADP is an index of risk to

[11] Using GADP average in some cases results in somewhat lower effect and significance levels.

investments, that is, if for example corruption has a low acceptance in a country the risk index for widespread corruption having a negative effect on the stability is larger than for the same corruption in a country that has a high tolerance for corruption (Lambsdorff 2004). The assumption here though is that it is the bad economic institutions, not the low tolerance for it, which is detrimental to investments. *Figure 3* shows scatter plots of the relation between time to adoption of the ICT technologies and average CPI. The pattern is similar to that for GDP per capita and indicates a clear correlation but a large dispersion where countries with the same index vary in time to adoption. A higher index means better economic institutions which are correlated with shorter time to adoption, therefore a negative slope.

2.4 Financial institutions

Figure 4. Private credit - time to adoption of ICT technologies.



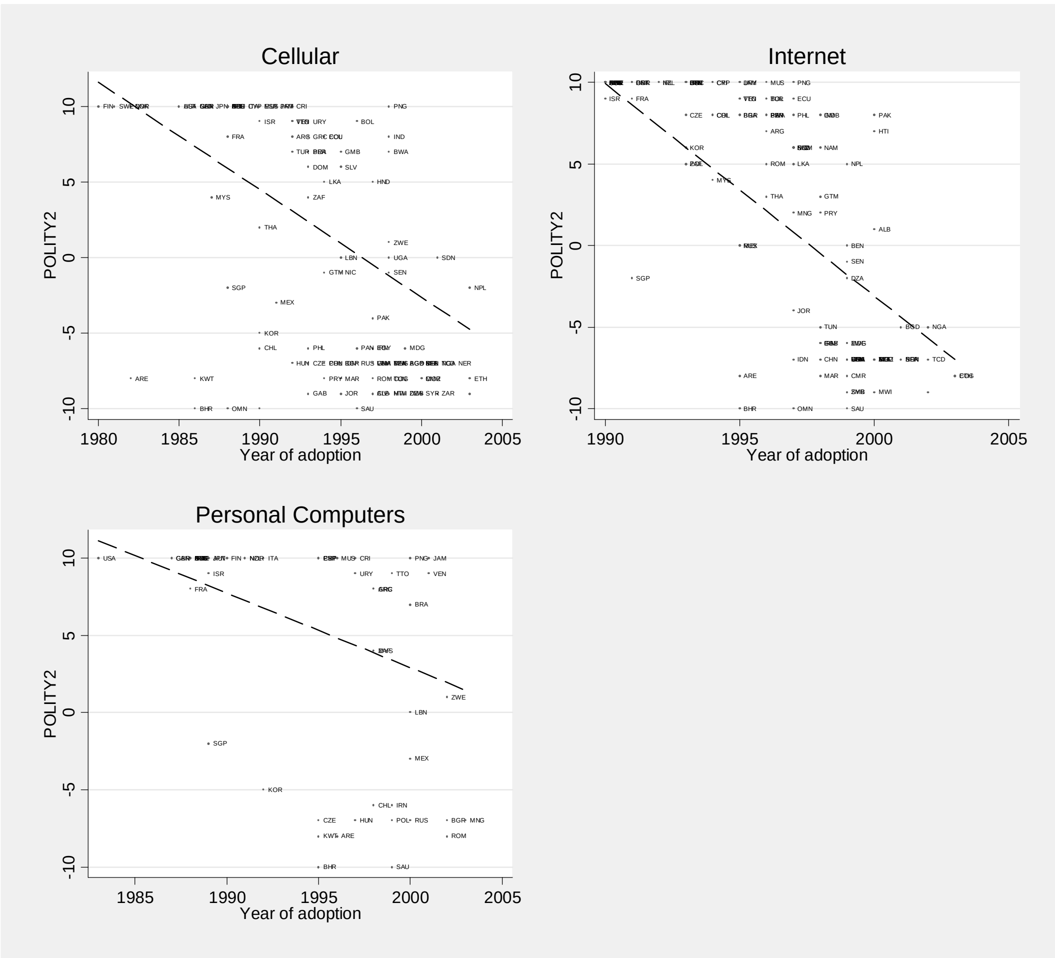
***Note**: Year of adoption calculated as the first year > 0.1% of the population has adopted the technology. For PC the threshold is > 5% of the population due to missing data for many countries below that level.*

High appropriability of the returns to investments is not sufficient to enable an entrepreneur to introduce new technology or companies and individuals to demand it. Investments also require a well functioning financial system which reduces transaction, enforcement and information costs which in turn increases the savings rate as well as the capacity to invest and innovate (Levin 2003). Also improved information will enable capital to flow to the projects with most potential for success. At the other extreme imperfect capital markets may hamper investment, both the size of feasible investments as well as the choice to invest at all (Aghion et al. (2004), Acemoglu and Zilibotti (1997)). Following Beck et al. (2000) the level of private credit by deposit money banks and other financial institutions to GDP (PCF) is used as a measurement of the quality of the financial system in a market. PCF measures how financial intermediaries channels savings to investors (Beck et al. 2000). *Figure 4* plots the relation between the availability of private credit and the time to adoption of the ICT technologies. There is a clear although less sharp correlation than in the case of GDP per capita and CPI. The dependent variable measures the number of users, mobile subscriptions, Internet subscriptions, PC:s, that is the demand for the service. In the case of PCF this is important since it could be argued that the suppliers, especially of mobile telephony and Internet access have the potential for attracting foreign capital. The local supply measured by PCF would then be irrelevant. The users, on the other hand, do not have this potential for accessing foreign capital. Mobile connectivity, Internet and PC:s are initially to a large extent demanded by firms using them as intermediate input in the production process or, in the case of Internet and PC:s, targeting them with content. If these local firms lack access to capital they can neither demand the new technologies nor create demand for them by supplying local content that makes the technologies more valuable to prospective adopters.

2.5 Political institutions

Political institutions affect the rules of the game as a result of either voter preferences or the preferences of the ruling fraction. The effect could be through for example taxation, patent regulation or trade regulations and tariffs. Different political institutions would assign different leverage to factions or groups within a country resulting in different policies on these issues. This in turn would affect the economic incentives for innovation and investment. The more “representative” the outcome of the political system, the more people will have the “correct” incentives for growth enhancing activities. Most of these effects would work through economic and financial institutions but some aspects, like personal freedom, could still directly affect the barriers to introducing new technology. To measure the political institutions in a country the POLITY2 index from the polity IV project is used. POLITY2 is a composite index measuring the degree of democratization versus autocracy in a country[12]. The span is from –10 to 10 where the lower the value the more autarchy and the higher the more democracy in a country. *Figure 5* shows a scatter plot of the relation between time to adoption of ICT technologies and POLITY2. Even though the linear correlation is not as pronounced as in the case of GDP per capita and CPI, there is a clear aggregation of countries in the upper left and lower right quadrant for cellular and Internet. For personal computers the relation is more unclear. There is an alternative index, Political Rights (PR) from freedom house that measures the extent of political freedom on a 7-grade scale. The correlation between POLITY2 and PR is 0.9 and none of the results are dependent on the choice of index.

Figure 5. POLITY2 - time to adoption of ICT technologies.



[12] See Marshall and Jagger (2002) for a detailed description of the different components of the index.

***Note**: Year of adoption calculated as the year > 0.1% of the population has adopted the technology. For PC the threshold is > 5% of the population due to missing data for many countries below that level. POLITY2 is constructed so that increasing values indicates higher quality political institutions.*

2.6 Education and Income

A common explanation of the delay in adoption of ICT technologies is that developing countries are poor and have a low level of education[13]. Therefore the correlation between time to adoption and quality of institutions will be tested controlling for the effect of GDP per capita and level of education. The primary measure of education used is the education index component of the Human Development Index from United Nations Development Program report. It measures a country's relative achievement in both adult literacy and combined primary, secondary and tertiary gross enrolment. An index giving adult literacy a large weight is used since the level of utility gained from each technology, mobile telephony[14], Internet and personal computers is to a large extent depending on level of literacy. The results are robust to the use of the Barro-Lee indexes for average years of schooling as well as average years of secondary schooling. Since most technologies will at least initially not be local the GDP per capita measurement is in current US$ without any PPP adjustment. Investment costs and necessary profit levels are supposed not to depend on the local cost level.

2.7 Data availability and multicollinearity

ITU data on time to adoption is available for between 160 and 200 countries. In the year 2003, measurement of economic institutions was available for 145 countries while for financial and political institutions it was available for 105 and 152 countries respectively. But for earlier years the data is not available for the full set of countries. When combining these different data sets in a panel suitable for duration analysis with time varying covariates there is a basic set of 82 countries where all variables are available[15]. In the case of cross-country OLS regressions the quality of financial or political institutions in 2003 probably does not affect a decision to invest or not invest in technologies made available almost twenty-five years earlier. For this reason, and to minimize the risk of simultaneity bias, data from close to the time of first availability of the ICT technologies is used in the cross-country regressions which also affect the availability of data. The overlap between available data for OLS and the

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[13] See for example Ciccone and Papaioannou (2005) for an empirical paper on the importance of human capital for technology adoption.
[14] Ease of use, SMS, WAP services.
[15] This is calculated at a threshold level of 1% adopters. The higher the threshold the larger the possible country set. In some cases forward fill is used, see notes on respective tables. Country list in appendix.

basic set of 82 countries is approximately 90% so to enable the use of the same dataset the remaining values are calculated using values from later years.

Table 1 : Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Average CPI	145	4.17	2.17	1.07	9.44
CPI	1316	5.02	2.58	0.00	10.00
Average GADP	129	30.43	9.89	11.08	49.79
GADP	1932	30.39	11.12	5.00	50.00
Private Credit	3017	0.40	0.35	0.00	1.81
POLITY2	3372	1.09	7.40	-10.00	10.00
GDP/capita[a]	3998	5.32	7.85	0.04	46.50
Education	936	7.24	2.14	0.93	9.93
Lag Cellular	199	1994.56	4.90	1980	2003
Lag Internet	193	1996.48	3.08	1990	2003
Lag PC	166	1993.63	4.46	1980	2003

a 1000$ US

***Note**: Summary statistics for the relevant variables 1980-2003. Lag Cellular, Internet and PC presented in calendar years for ease of interpretation. They indicate the year of adoption calculated as the first year >0.1% of population has adopted the technology. CPI and GADP constructed so that higher values mean higher quality economic institutions. POLITY2 negative values autocracy, positive values democracy. GADP available for 1983-1997. CPI available for 1980-2003, up to 1994 on a five-year basis. Education available on a five-year basis up to 1999.*

The correlation between the regressors is high (*see table 2)*, in the case of CPI and GDP/capita around 0.8.

Table 2 : Correlations

Variable	Average CPI	CPI	GADP	Private Credit	POLITY2	GDP/ capita	Education	ln (Lag Cellular)	ln (lag Internet)	ln (lag PC)
Average CPI	1.00									
CPI	0.91	1.00								
GADP	0.89	0.89	1.00							
Private Credit	0.66	0.67	0.66	1.00						
POLITY2	0.58	0.63	0.60	0.36	1.00					
GDP/capita	0.83	0.79	0.83	0.68	0.65	1.00				
Education	0.70	0.65	0.63	0.47	0.59	0.66	1.00			
ln(Lag Cellular)	-0.80	-0.69	-0.74	-0.50	-0.54	-0.76	-0.64	1.00		
ln(lag Internet)	-0.91	-0.82	-0.85	-0.65	-0.67	-0.82	-0.81	0.77	1.00	
ln(lag PC)	-0.45	-0.43	-0.47	-0.42	-0.39	-0.52	-0.55	0.38	0.54	1.00

***Note**: Correlations between the relevant variables. Cross sectional data from 1985. ln Lag Cellular, Internet and PC calculated as the natural log of the year >0.1% of population has adopted the technology minus the world wide inception year. CPI and GADP constructed so that higher values mean higher quality economic institutions. POLITY2 negative values autocracy, positive values democracy.*

3. Method

3.1 Basic model

The hypothesis to be tested is that quality of institutions affect time to adoption of ICT technologies. The data for institutions as well as income and to some extent education is available as panel data over time but time to adoption is by definition only available as cross country information. Given this limitation the simplest way to test the relation is in a cross-country regression, which is done in the basic model. This makes use of only part of the available data as well as requires some limiting assumptions on parameters but makes for results that are easy to interpret. In the case of economic institutions there are no significant trends over time nor large variations in the data so to increase the number of measurements averages over time are used. For the other institutional indexes (as well as income and education levels) the values from the time of the inception of each technology are used. These indexes are regressed on time to ICT adoption, (Lag_{ICT}). The following basic regression model is used:

$$\ln(Lag_{ICT})_i = \beta_0 + \beta_1 \cdot CPI_i + \beta_2 \cdot PCF_i + \beta_3 \cdot POLITY2_i + \beta_4 \cdot X_i + u_i \quad {}_{ICT \in \{Cellular, Internet, PC\}} \quad (1)$$

X is a vector of control variables including GDP per capita and education as well as other variables discussed in section 5.1. i is a country index. Time to adoption (Lag_{ICT}) is entered as a log value to ensure that it cannot take a negative value.

The way to calculate the value of the Lag_{ICT} has been to set it to the year the number of users in a country exceeds a certain percentage for the first time minus the year the technology was first commercialized. In regression (1) the percentage value used is 0.1% of the population. Since virtually all countries have reached a penetration rate of 0.1% for the three ICT technologies by 2003 (the last year of available data) there is no right censoring of the data and a simple cross-country OLS regression is feasible for estimating the basic model.

Not only the time to adoption is important but also the adoption rate once the technology is adopted. To analyze the diffusion rate of the ICT technologies once they are introduced a second regression is used:

$$ICTGrowth_i = \beta_0 + \beta_1 \cdot CPI_i + \beta_2 \cdot PCF_i + \beta_3 \cdot POLITY2_i + \beta_4 Lag_{ICTi} + \beta_5 \cdot X_i + u_i \quad {}_{ICT \in \{Cellular, Internet, PC\}} \quad (2)$$

ICTGrowth is calculated as the (average) change in adoption level during the first 5 years after adoption $\frac{1}{5}\sum_{t=1}^{5}(A_{it} - A_{it-1})$ where A_{it} is the adoption level in country i at time t. For countries that adopted after 1998 the average over available data is used. This is regressed on the same institutional variables as in the previous regression but also the year of adoption is included in the regression. X is as before level of education and GDP per capita. Except for CPI the data is from the year of adoption.

3.2 Duration Analysis

The basic model only makes use of a cross-section of the data and requires the threshold for adoption to be as low as 0.1%. To provide additional evidence using the entire available panel of data as well as testing the effects of using different adoption thresholds a second model more suitable to handle the data, a duration model[16] is introduced. In this type of model the full panel of available institutional variables at each year until adoption of the technology in a country is taken into account. Also the adoption-threshold can be varied in steps from 1% to 20% since duration analysis is much less sensitive to right censoring. The resulting coefficients measure the partial effect of changes in the covariates on the probability of adoption during a year conditional on not having adopted earlier.

$\Pr_i\left\{A_{it} \geq Z \middle| \ (A_{it-1}, A_{it-2}, ..., A_{i1} < Z), Y_{it}\right\}$ where A_{it} is the adoption rate for country i at time t, Z the adoption threshold used and Y_{it} the covariates for country i at time t. The regression model is as follows:

$$h(t)_{iICT} = h_0(t)_{ICT} \cdot e^{\beta_0 + \beta_1 \cdot CPI_{it} + \beta_2 \cdot PCF_{it} + \beta_3 \cdot POLITY2_{it} + \beta_4 \cdot X_{it}} \qquad ICT \in \{GSM, Internet, PC\} \qquad (2)$$

h_{0ICT} is a probability of adopting the ICT technology (conditional on not having adopted it before) equal for all countries called the base line hazard. One could think of this as similar to the assumption of free dissemination of ideas. All countries know about the existence and advantages of ICT technology and everything else equal should have an equal interest and thus probability of adoption. The exponential term then represents how institutions and other country specific (X) barriers to adoption affect this probability (multiplicatively) resulting in the country specific probability $h(t)_i$ [17] of adoption. The coefficients are calculated on a

[16] Duration analysis is commonly used in labour economics and to some extent in empirical work on technology diffusion. See for example Wooldridge (2002) ch. 20 or Kalbfleisch and Prentice (2002) for a text book treatment of Duration Analysis and van den Berg (2001) p. 3384 for a number of references on applications of duration analysis in labour economics as well as other fields in economics.

[17] This probability is the hazard rate $h(t)$ which is the (limiting) probability that the event occurs in a given interval, conditional upon that it has not yet occurred, divided by the with of the interval.

panel[18] using maximum likelihood, maximizing the probability of exactly the number of actual adoptions each year. This is done using the available data from the availability of the technology until 2003, the last year of available data, and takes into account the censored observations. Information on time to adoption of the ICT technologies is available yearly while CPI and Education is available only on a five years basis for 1980-1994 (education up to 1999). To take maximum advantage of the yearly ICT data, approximated values are used for CPI and education in the intertwining years by simply forwarding values from previous years. Since especially CPI is very persistent over time and the model is not using within-variation this is deemed acceptable. For the regressions Cox proportional hazard estimation is used. It is a method that estimates the effects of the covariates on the probability of adoption only relative to the unknown base line hazard but the advantage is that it is not necessary to make any assumptions on the distribution of Lag_{ICT}.

To gain additional information on the diffusion of ICT technology and it's relation to institutions it is possible to estimate how the base line hazard evolves over time. If the base line hazard increases over time, positive duration dependency, the common probability of adopting a technology increases. In this case the implications would be that sooner or later, no matter how bad the state of the economy or institutions in a country, the probability of adoption for the country would become very high. This would then cause the adoption rate in the world to become close to a hundred percent. If on the other hand there is negative duration dependency there is the possibility of a fairly stable state[19] with two groups, adopters and non-adopters. The non-adopters would be those countries that has not yet adopted at a time when the base-line hazard sinks to a level that is so low that no matter how high is the income or quality of institutions in a country, they would still not adopt. To study which, if any, of these possibilities matches the data the behaviour of the base line hazard over time will also be analyzed.

$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t + \Delta t > T > t)}{\Delta t} = \frac{f(t)}{1 - F(t)}$ The coefficients shown are the exponentiated values so for a coefficient of for ex. 1.21, 1 step increase in the related index would mean a ~1.21 times (~21%) higher probability of adoption. Significance level is approximately the Wald test that 1.21 is different from 1.

This model is directly related to regression model (1) which also could be written as $Lag_{ICT\,i} = e^{\beta X_i + u_i}$. When using OLS regression (1) also requires the assumption on log-normal distribution of the errors which is not needed when using Cox PH estimated with maximum likelihood in duration analysis.

[18] The panel is unbalanced. Especially for early years data is missing for a number of countries.

[19] Of course, in the long run all countries would still adopt but for practical purposes the long run could be much longer than the life-span of the technology.

4. Results

For ease of exposition, in the basic cross-country regression I will first show the results for Cellular and then discuss Internet and personal computers at the end. Endogeneity issues are discussed in depth in chapter five.

4.1 Basic results

The basic results are based on cross-country OLS estimations. The time to adoption of mobile telephony is regressed on the quality of institutions, controlling for the impact of GDP per capita and level of education. The results are presented in *table 3.* In column 1 the quality of economic institutions, measured by average CPI, is regressed on time to adoption of cellular technology. The coefficient is significant with a negative sign which shows that higher values of CPI (better quality economic institutions) are significantly correlated with shorter time to adoption of cellular technology. This is not surprising given the scatter plot in *figure 3.* When the other two indexes of financial and political institutions are entered in column 5 and 6, the partial effect of average CPI is significant at the 1% level and there is only a marginal reduction of the coefficient. Very little of the relation between economic institutions and time to adoption of cellular can be explained by controlling for other institutional factors. However in column 7 when GDP per capita and level of education is included, the coefficient of CPI, though still significant at the 5% level, decreases to a third.

Table 3: Institutional effect on time to adoption of cellular technology.

Variable	Cellular1	Cellular2	Cellular3	Cellular4	Cellular5	Cellular6	Cellular7
AverageCPI	-0.354***				-0.296***	-0.286***	-0.124**
	0.041				0.062	0.06	0.053
POLITY2		-0.266***			-0.064***	-0.066***	0.004
		0.043			0.022	0.022	0.021
PrivateCredit			-0.325***	-0.600***	-0.043	-0.207**	-0.297***
			0.049	0.143	0.054	0.085	0.076
PrivateCreditSq				0.089**		0.051*	0.103***
				0.039		0.027	0.028
GDPcapita							-0.274***
							0.06
Education							-0.044***
							0.016
N	82	82	82	82	82	82	82
r2_a	0.686	0.312	0.375	0.399	0.694	0.7	0.768

Data: *Basic country set of 82 countries. Values normalized by their standard deviation.*
Note*: The dependent variable Cellular is the log of time to adoption of cellular technology in a country calculated as the first year > 0.1% of the population has a subscription minus the inception year of cellular. AverageCPI is the average over available CPI data for the years 1980-2003. Other variables are cross-sectional data from 1985 except in 8.8% of the cases where values are extrapolated using later year values. Robust standard errors included.*

***Legend**: *significant at 10%; **significant at 5%; ***significant at 1%*

That there are large dependencies between economic institutions, GDP per capita and level of education is documented in a number of influential studies. Acemoglu et al. (2001, 2004) and Hall and Jones (1998) for example finds that quality of economic institutions proxied by, among other indexes GADP, affects growth while Chong and Calderon (2000) finds that there is also a significant effect from level of economic development to measurements of economic institutions. Glaesser et al (2004) on the other hand finds that level of education significantly affects the level of economic institutions. What can be seen here is that even when controlling for the effects of income and education, economic institutions are significantly correlated with time to adoption of cellular technology. That there is also a causal effect could be argued from the theoretical standpoint that adopting a technology at the 0.1% level, even an ICT technology, is not an event important enough to change something as persistent as institutions. The case that both time to ICT adoption and institutional quality could potentially be affected by some omitted variables is discussed in section 5.

Financial institutions, proxied by private credit, are significantly correlated with time to adoption of cellular both when entered directly in column 3 and also when the square is included in column 4. The reason to include the square, allowing for a non-linear correlation, is that previous research (Aghion et al. 2003) indicates that the importance of financial institutions decreases with the quality of those institutions. The result here supports those findings. When all three institutional variables are included in column 5 and 6 only the non-linear relation for private credit survives. Unlike the index for economic institutions the coefficients for private credit and private credit square changes only marginally when education and GDP per capita are included and they are still significant at the 1% level. The coefficients for private credit indicate that the partial effect on time to cellular adoption is quadratic and the maximum effect is attained inside the range of the data at less than one standard deviation above the mean value. Thus the quality of financial institutions is most important for countries with low to medium quality financial institutions but much less so for countries with high quality institutions[20]. In the case of private credit the available data allows the use of data from before the introduction of cellular in most countries. Thus the results show that the quality of financial institutions from before the introduction of cellular is

[20] This is well in line with Aghion et al. (2003) that finds that the increase in the positive effects of financial institutions on growth stops once a country has reached a certain level of financial intermediation (found to equal the level of Greece in their paper).

significantly correlated with the future time of adoption of the technology, making it even more plausible that there is a causal relationship from financial institutions to time to adoption of the technology.

In the case of political institutions, proxied by POLITY2, there is a significant correlation when only POLITY2 is entered (column 2). However once the other two institutional indexes as well as Education and GDP per capita are introduced in column 7 the level effects becomes very small and insignificant. If there is an effect of political institutions it is mainly indirect through economic and financial institutions[21] as well as through income and education.

I repeat the basic regression analysis using the other ICT technologies Internet and personal computers. *Table 4*, reports the results when all regressors (including controls) are included as in column 7 of *table 3.* The general results are confirmed but there are individual variations. The most interesting is in column 5 where the partial effect of POLITY2 is significantly correlated with time to adoption of Internet even when adding all controls[22]. What makes this ICT technology special is probably that one of the main targets of Internet technology is free information dissemination in a way that, at least previously[23], has been very hard to control for a central authority.

Table 4: Institutional effect on time to adoption of ICT technology.

Variable	Cellular 1	Internet 2	PC 3
AverageCPI	-0.124** 0.053	-0.061*** 0.015	0.056 0.057
PrivateCredit	-0.297*** 0.076	-0.095*** 0.024	-0.346*** 0.109
PrivateCreditSq	0.103*** 0.028	0.022*** 0.006	0.082** 0.034
POLITY2	0.004 0.021	-0.037*** 0.01	-0.002 0.034
GDPcapita	-0.274*** 0.06	-0.059*** 0.019	-0.173* 0.095
Education	-0.044*** 0.016	-0.046*** 0.011	-0.128*** 0.034
N	82	82	80
r2	0.768	0.905	0.5

[21] That there is an indirect link from different aspects of political institutions via economic and/or financial institutions affecting growth is suggested by Persson (2004), Feng Yi (2003) and Fidrmuc (2003).
[22] This result is robust also to the inclusion of a number of variables found to be significantly correlated to growth. See section 5.1.
[23] It is claimed that China (as well as some other regimes) are working quite successfully on a number of technical as well as organizational methods of addressing this issue. See for example http://www.opennetinitiative.net/studies/china/

Data: *Basic country set of 82 countries except for PC where there is no ITU information for Belarus and Kazakhstan. Values normalized by their standard deviation.*
Note*: The dependent variables Cellular, Internet and PC are the logs of time to adoption of respective technology in a country calculated as the first year > 0.1% of the population had adopted the technology minus the inception year of the technology. AverageCPI is the average over available CPI data for the years 1980-2003. Other variables are cross-sectional data from 1985 for Cellular and PC and 1990 for Internet. 7.7% of the values are missing and are extrapolated using later year values. Robust standard errors included.*
Legend*: *significant at 10%; **significant at 5%; ***significant at 1%*

In column 3 average CPI is not significantly correlated with time to adoption of personal computers. This is most probably an effect of deficiencies in the data set where very steep initial values for a large number of countries indicates that data collection was not efficient at low values of adoption. This effect disappears once the adoption threshold is increased above 1% as is shown in the next chapter.

The values of the independent variables are normalized by their standard deviation and the regression is log-normal. The coefficients in *Table 4* can therefore be interpreted as the approximate partial percentage effect of a one standard deviation change in the independent variables on time to adoption. The level effects vary both between technologies and between the different institutional variables. The partial effect of a one standard deviation of CPI is largest in the case of cellular where it is also almost half that of GDP per capita and much larger than that of education. In the case of Internet the percentage effect is half that for cellular but larger than the effects of both GDP per capita and education. For private credit the partial effect is larger than both GDP per capita and education for all three technologies. However due to the non-linear effects of private credit this is true only for low levels of private credit. At one standard deviation the effects are negligible. The coefficients for POLITY2 is significantly different from zero only in the case of Internet but here the level of the partial effect is comparable to that of all the other variables. The overall conclusion is that the importance of quality of institutions for explaining time to adoption of ICT technologies are of the same magnitude as income and education.

Table 5: Effect of time to adoption on rate of adoption.

Variable	Diffusion Cellular	Diffusion Internet	Diffusion PC
CPIAverage	4.012	1.886	4.304**
	2.586	1.137	1.929
PrivateCredit	-3.068	0.062	4.194*
	2.723	1.407	2.107
PrivateCreditSq	0.606	0.313	-1.494**
	0.648	0.331	0.714
POLITY2	1.588	-1.072	0.391
	1.109	0.954	0.645

GDPcapita	-1.559 1.741	-0.276 0.965	7.215*** 2.43
Education	3.307*** 0.898	3.563*** 1.21	1.233 0.796
Lag Cellular	5.974*** 1.947		
Lag Internet		2.920** 1.168	
Lag PC			4.037*** 1.259
N	82	82	80
r2	0.317	0.382	0.803

Data: *Basic country set of 82 countries except for PC where there is no ITU information for Belarus and Kazakhstan. Values normalized by their standard deviation.*
Note*: The dependent variables Diffusion Cellular, Internet and PC are the average increases in the number of adopters over the first five years (or fewer if adoption after 1998)* $\frac{1}{5}\sum_{t=1}^{5}(A_{it}-A_{it-1})$ *. AverageCPI is the average over available CPI data for the years 1980-2003. LagICT is the year of adoption. Other variables are cross-sectional data from the year of adoption for each country. Robust standard errors included.*
Legend*: *significant at 10%; **significant at 5%; ***significant at 1%*

Not only time to adoption is important for access to new technology in a country but also the adoption rate once the technology is adopted matters. In the next regression the average increase in the number of adopters during the first five years is regressed on the different proxies for institutional quality as well as education and GDP per capita but also the time of adoption is included. The result, in *Table 5*, shows that the time of adoption is the single most important factor[24] in explaining the adoption rate. The later a country adopts an ICT technology, the faster is the adoption rate during the first five years. This means that late comers partly make up for lost time by embracing the new technologies faster. In the case of both cellular and Internet none of the institutional variables enter significantly in the regression nor does income. Only time to adoption and level of education matters. In the case of personal computers CPI, private credit and GDP per capita is equally important as time to adoption while education is insignificant. But in all cases time to adoption plays a significant role in explaining the rate of technology diffusion once the first barriers to technology adoption is breached. The more mature is the technology, the faster it spreads in a country.

4.2 Duration analysis

In the previous basic regressions a threshold of 0.1% users in the population is used for determining if a country has adopted a technology. The reason is to avoid right censoring thus enabling the use of OLS and a simple to interpret log-normal regression model. But adoption

[24] Of the explanatory variables included of course. Since r2 is quite low there is also other explanations that matters.

by 0.1% of the population could be very different from adoption by 10%-20% of the population. In most countries there is a small elite of fairly rich, educated and technology savvy people where the type of barriers to technology adoption might be quite different from those affecting time to adoption for a broader part of the population. Since the main reason for studying the causes of those barriers is the assumed effect of improved technology on productivity and growth, it is important to understand if the previous results hold also when looking at time to adoption for large parts of the population that could have a substantial impact on productivity and growth. To further analyze the data using different values for the adoption breakpoints as well as the full panel of available data, an estimation according to model 3 is done using Cox Proportional Hazard and time-varying covariates (panel data). The results are shown in *Table 6* where the effects of institutions on the probability of adopting ICT technology for breakpoints of 1%, 5%, 10% and 20% are presented.

When looking at the partial effect of CPI on time to adoption the coefficients are significantly different from zero and has the correct coefficient (larger than 1) which show that the quality of institutions are related to time to adoption of all three ICT technologies also at higher adoption levels. The effects however are not uniform at all adoption levels. In the case of cellular and PC the level of the effect show an inverse U trend with a maximum at 10% in the case of cellular and 25% in the case of personal computers. The effect of economic institutions on adoption time is largest when taking the step from early adopters to a larger set of the population[25]. In the case of Internet on the other hand the effect is fairly stable for the different adoption levels. The reason could be that the introduction of Internet is more driven by demand from new companies using the Internet as their channel towards customers thus starting with no existing customer base.

Private credit and private credit squared has the correct coefficient, higher than one for private credit and lower than one for private credit squared. It is only for the cellular technology though that the coefficients are significant for adoption thresholds higher than 5%[26]. For the other two technologies the quality of financial institutions has a significant impact only in the initial stages of adoption. Once the technology becomes more widespread, the importance of external financing diminishes.

[25] What has popularly been called “crossing the chasm” in the management literature.

[26] Cellular technology requires extremely large investments in infra-structure to increase capacity and coverage which could be one explanation for the differences in the pattern of the effect of financial institutions.

The effect of POLITY2 is somewhat similar to that of private credit. It is significantly different from zero for breakpoints of 1% for all three technologies albeit at a very low level. This indicates the possibility of a small direct effect of political institutions at the initial stages of technology adoption. Except in the case of cellular, once a technology has gained a beachhead in a country the political institutions does not seem to have any direct impact on the adoption anymore.

Thus the quality of institutions does affect the time to adoption of all three ICT technologies but not in any common pattern. Each technology shows different sensitivity to all three institutional effects during different stages of the adoption process. The level and even the presence of any effect vary as more and more people adopt the technologies. An interesting observation is that education follows the same inverse U trend as CPI but with even higher coefficients at the 10% and 20% adoption levels for Internet and personal computers. The education index is to a large extent measuring adult literacy and the result probably reflects the dependency of both technologies on reading and writing skills for maximum utility (when using only the total years of schooling component the large effect disappears).

Table 6: Institutional effect on probability of adopting ICT technologies

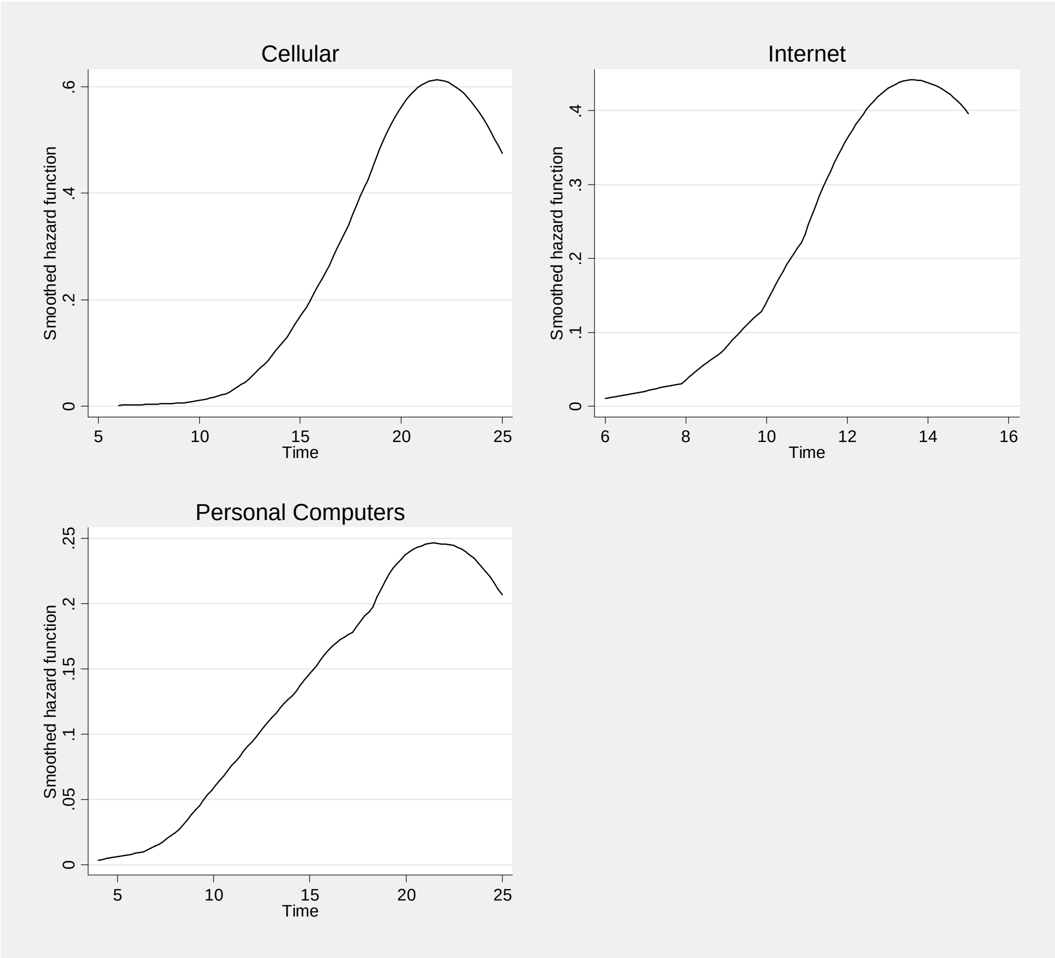
ICT Technology Adoption threshold	Cellular 1%	Cellular 5%	Cellular 10%	Cellular 20%	Internet 1%	Internet 5%	Internet 10%	Internet 20%	PC 1%	PC 5%	PC 10%	PC 20%
CPI	1.39*	2.21***	2.66***	1.81**	3.44***	2.27***	2.77***	2.76***	1.54*	2.25***	5.60***	4.39***
PrivateCredit	2.49***	2.26***	1.85**	2.61***	2.78***	2.05**	1.59	1.17	2.27**	1.27	1.87	1.94
PrivateCreditSq	0.84***	0.85***	0.87**	0.83**	0.86**	0.88	0.93	0.97	0.86*	0.94	0.86*	0.85
POLITY2	1.44***	1.65***	1.51**	1.46	1.59***	1.03	1.42	1.16	1.42*	1.63	1.98	0.62
Education	2.08***	2.10***	3.63***	2.91**	3.13***	2.90***	11.32***	6.87***	2.56***	5.82***	3.49*	11.61***
GDPcapita	2.11**	1.92**	1.82**	2.35***	1.55**	2.11***	1.66**	1.56**	1.12	1.95**	1.96***	2.85***
N	743	953	1036	1105	487	668	725	762	628	880	1000	1106
Nr of subjects	82	82	82	82	80	82	82	82	69	77	80	80
Nr of adoptions	81	63	55	44	71	61	38	30	63	55	36	25

Data: *Basic panel of 82 countries except for PC where there is no ITU information for Belarus and Kazakhstan. Values normalized by their standard deviation. Since some values are missing for early years not all countries are included for low levels of the adoption threshold.*

Note*: Cox proportional hazard regression of the institutional effect on the probability of adopting Cellular telephony, Internet and PC. Adoption calculated as the time period when more than 1%, 5%, 10% or 20% of the population had adopted the technology. Panel of available data 1980-2003. CPI and education available on 5 year basis 1980-1994 (education 1998). Missing data substituted using forward fill where possible. Exponentiated coefficients shown.*

Legend*: *significant at 10%; **significant at 5%; ***significant at 1%.*

Figure 6: Estimated baseline hazard function



***Source**: Authors calculations'. Data from regressions in table 6.*
***Note**: Estimation of the baseline hazard function from Cox proportional hazard regressions of institutional impact on cellular, Internet and personal computers. Adoption threshold used 0.1%. Time is analysis time in years. Smoothed.*

When using duration analysis the effect of institutions is calculated as an offset (relative hazard) from a base line hazard common to all (see model (2)). This base line hazard is the common probability of adopting a new technology and is plotted over time in *figure6* for the three different ICT technologies. It has approximately the same form for all three technologies, increasing (positive duration dependency) until a maximum and then decreasing during the final years. This means that when a technology matures, the probability of adoption increases regardless of the quality of institutions as well as levels of income and education until finally all countries will adopt the technology[27]. The reasons could be both external to

[27] This observation fits well with the models of Parente and Prescott (1994) and Caselli and Coleman II (2004) where barriers to technology adoption diminishes with the distance to the technology frontier.

the technology like network effects and spreading knowledge of the technology as well as internal in the form of micro inventions lowering the barriers to adoption.

Summing up the results the two methods used, OLS and Duration Analysis, shows that all three institutional aspects play a role in the time to adoption of the ICT technologies. The pattern of this impact though is different.

- Economic institutions are increasingly important up to an adoption level of 10% and then show signs of diminishing. For personal computers economic institutions are not important at all at low adoption levels. One could speculate that either the first computer adopters are not in business related areas and thus not as negatively affected by low quality institutions or that reporting of low levels of computer usage is not effective.
- Financial institutions are important for countries with a low level of financial development. Once a country has reached a more mature stage of financial development it does not seem to play any further role for time to technology adoption. Except in the case of cellular, financial institutions are only important in early stages of technology adoption when users are few. Once a certain user base is reached, external financing is not as important.
- Political institutions, except in the case of Internet, have only a small direct impact on time to adoption and mostly in the initial stage. For Internet the impact is larger but still only in the initial stage of adoption.

5. Robustness issues

5.1 Simultaneity bias

In growth regressions there is always a risk of simultaneity bias. Good institutions cause a high level of income but a good economy would also enable better institutions. Here the dependent variable is the time to adoption of a single technology not GDP per capita. The possibility that the adoption (at the 0.1%-20% level) of an ICT technology should influence factors as persistent as institutions to any significant degree is not in any way as plausible as the possibility that the state of the total economy should impact the quality of institutions. In the case of regression model (1) the institutional values (except in the case of CPI) from the years prior to adoption are used for the majority of countries. This should strengthen the case for a causal relation from quality of institutions to time to ICT adoption.

5.2 Omitted variable bias

A more serious problem is that some factors not accounted for in the regression might affect the ability of a country to adopt new technology at the same time as they affect the quality of institutions. This leads potentially to an omitted variable problem. Since it is reasonable to assume that such a variable would also affect the economic growth of a country, one way to control for this is to control for factors found significant for growth by other studies. Since it is impossible to make such an exercise exhaustive it more serves the purpose of making the overall argument more plausible. The variables used are those found important for growth in Barro (1991, 1996) and Sala-i-Martin et al. (2000)[28]. The problem with this approach is the low number of degrees of freedom left when including a large number of variables in the regression. Especially since a number of these variables are not available for all countries in the regression. The *table 7* shows the results, first without controlling for growth variables, column 1, and then when adding the growth variables, column 2-4. In the case of cellular all institutional indexes that are significant in the base regression in column one are significant (albeit at a lower level) when adding the different growth variables in column 2-4. The coefficients are fairly stable at approximately the same level[29].

[28] See the appendix and/or references for a list of the variables.

[29] The aim of these regressions is to make plausible that the main results are not driven by omitted variable bias. It is not a further exercise in data-mining. Some more in-depth information is added here just as background information. In *table 6* for the Xavier data the r2 value increases significantly, an effect mainly caused by the addition of a variable for the percentage of protestants in the population and to a lesser degree the exchange rate distortions. This indicates that something measured by these variables explains time to adoption of cellular technology in addition to institutions, education and growth

Table 7: Controlling for growth variables.

Variable	Cellular 1	Cellular Barro1	Celllular Barro2	Cellular Xavier
AverageCPI	-0.068**	-0.046*	-0.072**	-0.048*
	0.026	0.027	0.032	0.027
PrivateCredit	-0.711***	-0.658**	-0.738**	-0.702**
	0.261	0.307	0.321	0.271
PrivateCreditSq	0.742***	0.700***	0.758**	0.527**
	0.234	0.25	0.291	0.235
POLITY2	0.001	0.001	-0.001	-0.005
	0.003	0.004	0.003	0.004
Education	-0.036***	-0.011	-0.021	-0.025
	0.011	0.017	0.021	0.017
GDPcapita	-0.030***	-0.033***	-0.031***	-0.015
	0.008	0.01	0.009	0.01
N	83	72	73	77
r2	0.772	0.789	0.784	0.833
Variable	Internet	Internet	Internet	Internet
AverageCPI	-0.036***	-0.032***	-0.033***	-0.030***
	0.007	0.007	0.006	0.007
PrivateCredit	-0.141**	-0.130*	-0.144*	-0.186***
	0.066	0.074	0.075	0.062
PrivateCreditSq	0.099*	0.087	0.090*	0.121**
	0.05	0.054	0.052	0.046
POLITY2	-0.005***	-0.004***	-0.005***	-0.004***
	0.001	0.001	0.001	0.001
Education	-0.026***	-0.022***	-0.023***	-0.022***
	0.004	0.006	0.006	0.004
GDPcapita	-0.006**	-0.006**	-0.005**	-0.004
	0.002	0.003	0.002	0.003
N	88	78	78	81
r2	0.924	0.93	0.937	0.941
Variable	PC	PC	PC	PC
AverageCPI	0.02	-0.006	0.02	0.023
	0.026	0.036	0.032	0.037
PrivateCredit	-0.821**	-0.970**	-1.074**	-0.978**
	0.326	0.442	0.457	0.406
PrivateCreditSq	0.478*	0.601*	0.657*	0.760**
	0.284	0.352	0.379	0.345
POLITY2	-0.004	-0.004	-0.002	-0.001
	0.005	0.006	0.006	0.006
Education	-0.043*	-0.038	-0.054	-0.038
	0.024	0.033	0.038	0.026
GDPcapita	-0.019*	-0.021	-0.022	-0.037**
	0.011	0.014	0.013	0.018
N	80	71	70	74
r2	0.481	0.563	0.489	0.539

***Note**: The dependent variable Cellular is the log of time to adoption of cellular technology in a country calculated as the first year > 0.1% of the population adopted the technology minus the inception year of the technology. AverageCPI is the average over available CPI data for the years 1980-2003. Other variables are cross-sectional data from 1985. Robust standard errors included. Column Barro1, Barro2, Xavier includes variables found significant for growth in Barro (1991), (1996), Sala-i-Martin et al. (2000). Coefficients not shown.*

***Legend**: *significant at 10%; **significant at 5%; ***significant at 1%*

In the case of Internet the results are similar except in the case of private credit that is barely significant when adding the Barro growth variables. The values of the coefficients for both private credit and private credit squared are still not changing making it quite plausible that the loss of 10 observations as well as 6 degrees of freedom is the main cause. For personal computers the results are not significantly altered when controlling for the growth variables[30]. The overall conclusion is that the previous results are robust to controlling for the different sets of growth variables. The results are not driven by any omitted variable bias caused by omitting any of the growth variables found in previous work.

A variable potentially causing an omitted variable bias should be expected to work on a country level as well as to be fairly constant or trending over time. This enables a second way of testing if the results are driven by omitted variable bias. The inclusion of country fixed effects and time dummies should remove the impact of any unobserved effects but since the time to adoption (Lag_{ICT}) is constant over time it is not possible to use in a fixed effect regression. If one assumes that adoption level is increasing over time which is the case in almost all countries, the level of adoption would be proportional to time of adoption and time varying. The log of this value is used in the following fixed effect regression:

$$\begin{aligned}\ln(A_{ICT})_{it} = \beta_0 + \beta_1 \cdot GADP_{it} + \beta_2 \cdot PCF_{it} + \beta_3 \cdot POLITY2_{it} + \beta_4 \cdot Education_{it} + \\ \beta_5 \cdot GDP/Capita + d_t + a_i + u_{it}\end{aligned} \quad (4)$$

The GADP index of economic institutions is used as proxy for economic institutions instead of CPI since being the result of an evaluation by one firm it is expected to reflect changes over time more consistently[31]. d_t is time dummies and a_i country fixed effects[32].

The coefficients for GADP and private credit in *table 8* are significant at the one percent level and of the correct sign. Both the effects of economic as well as financial institutions are stable to controlling for country fixed effects. POLITY2 on the other hand has the wrong sign in the

[30] See previous note. Here the inclusion of the Xavier data has the effect of increasing the r2 value. This result is not driven by any special variable but almost all included variables ad to the effect in a fairly equal fashion.

[31] All variables except Education is available yearly. Education is available on a five year basis and values for the missing years are forwarded from the closest previously available value. This is deemed acceptable since the coefficient for education is not a focus here.

[32] The index used for economic institutions is GADP, which is available for a different set of countries than CPI used previously. The possible overlap with the set of 82 countries used earlier is a set of 76 countries. The results shown are from all available observations resulting in a set of approximately 100 countries. Restricting the set to the 76 countries in the previous dataset does not change the main results but do lower some significance levels.

case of Internet and PC and the results are highly significant. An improvement in political institutions seems to indicate a negative effect on the time to adoption of the ICT technologies.

Table 8: Fixed effects regression.

Variable	Cellular 1	Internet 2	PC 3	Cellular 4	Internet 5	PC 6
gadp	1.487*** 0.371	2.453*** 0.557	1.094*** 0.404	1.371*** 0.373	2.376*** 0.568	1.157*** 0.411
PrivateCredit	1.663** 0.646	3.052*** 1.016	2.751*** 0.744	1.753*** 0.648	3.242*** 1.003	2.803*** 0.748
PrivateCreditSq	-0.346** 0.145	-0.369* 0.204	-0.507*** 0.165	-0.347** 0.146	-0.379* 0.203	-0.504*** 0.166
POLITY2	0.092 0.266	-1.264*** 0.407	-1.018*** 0.304			
l4POLITY2				1.347*** 0.252	0.929** 0.365	-0.361 0.294
GDPCapita	0.529 1.073	-10.211*** 2.131	5.681*** 1.08	1.182 1.063	-8.983*** 2.119	6.052*** 1.087
Education	-6.767*** 1.453	-4.526* 2.307	-4.457*** 1.482	-5.300*** 1.437	-5.050** 2.37	-4.262*** 1.556
N	1379	742	1377	1367	731	1365
r2	0.759	0.807	0.723	0.763	0.806	0.718

***Note**: Fixed effect regression of institutional effect on distance to technology frontier. Dependent variables Cellular, Internet and PC measured as current adoption. Panel of available data 1983-1997 restricted by availability of GADP. Education available on 5 year basis, forward fill used to fill gaps. .l4 POLITY2 lagged 4 years using data from 1979-1993. Values normalized by standard deviation.*
***Legend**: *significant at 10%; **significant at 5%; ***significant at 1%*

The fixed effects regression assumes a direct and yearly effect between institutions and time to adoption of ICT technologies. In the case of GADP and private credit this assumption is plausible. GADP is an index compiled by different country experts. Their opinion is based on leading indicators available also to entrepreneurs active within the country. Thus a change in the index is based on a previous change in economic institutions apparent to economic actors and should already be discounted in their actions. Private credit measures the amount of credit currently available, which means that it is already in use by entrepreneurs. In the case of POLITY2 though, a more plausible scenario is that the effects are lagged and requires substantial time to take effect. Papaioannou and Siourounis (2004) for example[33] studies the impact on growth of democratization[34] in a country and finds that the curve is j-shaped with the positive effects entering after approximately 3 years while the early effects are negative.

[33] Also Pettersson (2004) and Persson (2005) find that the duration of democratization positively affects the growth effects.
[34] They study within effects of countries changing into a democracy.

The results of the regression using a POLITY2 value lagged 4 years[35] are shown in *table 8 columns 4-6*.

The effect of POLITY2 now has the correct sign and is significantly different from zero in the case of cellular and Internet. In the case of PC the coefficient still has the wrong sign but is smaller and not significantly different from zero. The conclusion is that after a stabilizing period the long run effects of democratization are positive also when controlling for fixed country effects.

As can be seen from *figure 1* the diffusion rate of the three ICT technologies is very fast. In the time span of 15 to 25 years they have spread over almost the entire globe. To capture this rapid expansion, yearly data is used in the fixed effect regression, which also allows the capture of the effect of POLITY2. If 3 or 5[36] years averages are used POLITY2 is again negative and insignificant while the effect on GADP and private credit is mainly to decrease the level of significance while the levels of the coefficients are relatively stable.

If the regressions are run without controlling for country effects, (a_i) in (4) above, the coefficients for the effects of the institutional indexes are not statistically different at the 5 percent level from those found when controlling for country fixed effects[37]. It is thus very plausible that omitted country effects do not significantly affect the correlations found between institutional indexes and adoption rates in the different countries. Since time to adoption, the dependent variables in the main regressions, is calculated using these adoption rates this also indicates that those results are not driven by omitted country effects.

6. Concluding discussion

The quality of institutions matters for the adoption rate of ICT technologies at a level comparable to that of income and education. A substantial part of the “Digital divide” can thus be explained by the quality of institutions. But is the policy lesson here that improved institutions is a road to faster adoption of new technologies in developing countries? Certainly it is one lesson, but this does not really come as a surprise to most people interested in development questions. Another interesting possibility emanating from the data is that

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[35] Changing the lag ± 1 year does not significantly change these results.
[36] 5 years average is not possible in the case of Internet.
[37] The only exception is lagged POLITY2 in the case of cellular when restricting the dataset to 76 countries (see note 29).

different technologies appear to have different sensitivity to the quality of economic, financial and political institutions (as well as to the level of education and income) during different stages of the technology's life cycle. Understanding what aspects of the design of a technology makes it more or less sensitive to the quality of institutions as well as to the level of income and education would enable technology and design choices that are more robust to these factors. Of course this would also require an understanding of the mechanisms that causes R&D departments to choose one or the other technical solution. Barriers to technology adoption caused by bad institutions (as well as the other factors) could then also be influenced with R&D policies as well as more proper technology choices.

Two changes to the adoption process over time are worth mentioning. First, as could be seen from *figure 6,* the process exhibited positive duration dependency: the ceteris paribus probability of adoption increased over time. Secondly, the results in *table 5* show that the later a country adopts an ICT technology, the higher is the adoption rate. Since time itself does not cause changes this indicates that something changes in the technology or the conditions for adoption or both making adoption more plausible the more mature is the technology. Understanding what these changes are other than the trivial effect of lower prices might enable the creation of technologies that are easier to adopt as well as understanding what conditions are most beneficial to adoption.

This paper shows that for the three ICT technologies considered the quality of institutions temporarily influence technology adoption and thus is an important cause of the technological divide. If the results here were typical for technology adoption in general, inadequate institutions would affect aggregate growth through delayed productivity improvements. This would then be an important channel for the effect of institutions on growth.

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8. Appendix 1

Variables

Lag_{ICT}

The source for the calculations is International Telecommunications Union (ITU), Yearbook of Statistics (Geneva),

- Cellular subscribers per 100 inhabitants (ITU estimates)
- Internet users per 100 population (ITU estimates)
- Personal computers per 100 population (ITU estimates)

Quality of Institutions

- *Corruption index*

  Corruption Perception Index from Transparency International. The CPI is a composite index, making use of surveys of businesspeople and assessments by country analysts. The number of sources varies somewhat from year to year. 2004 there were data from18 surveys and 12 institutions used as a base for the index. Yearly data from a large number of countries (145 in 2004) has been available since 1995. In earlier periods data is available only for a limited number of countries approximately as a 5 year average. The weighing process of the index makes use of a smoothing process and different statistical methods to improve the properties of the index. For a complete description please see Lambsdorff (2004).
- *GADP*

  Annual values 1982-1997 of quality of governance indicators weighted into an index using equal weight average of indicators (Law and order, Bureaucratic quality, corruption, risk of expropriation, government repudiation of contracts) in International Country Risk Guide from Political Risk Service. The different indexes are described as follows:

  Excerpts from variable descriptions, International Country Risk Guide:

  1. Corruption in Government

     Lower scores indicate, "high government officials are likely to demand special payments" and that "illegal payments are generally expected throughout lower levels of government" in the form of "bribes connected with import and export licenses, exchange controls, tax assessment, police protection, or loans."

2. Rule of Law (named “Law and Order Tradition” in ICRG)
   This variable "reflects the degree to which the citizens of a country are willing to accept the established institutions to make and implement laws and adjudicate disputes." Higher scores indicate: "sound political institutions, a strong court system, and provisions for an orderly succession of power." Lower scores indicate: "a tradition of depending on physical force or illegal means to settle claims." Upon changes in government new leaders "may be less likely to accept the obligations of the previous regime."
3. Quality of the Bureaucracy
   High scores indicate "an established mechanism for recruitment and training," "autonomy from political pressure," and "strength and expertise to govern without drastic changes in policy or interruptions in government services" when governments change.
4. Risk of Repudiation of Contracts by Government
   “This indicator addresses the possibility that foreign businesses, contractors, and consultants face the risk of a modification in a contract taking the form of a repudiation, postponement, or scaling down" due to "an income drop, budget cutbacks, indigenization pressure, a change in government, or a change in government economic and social priorities." Lower scores signify "a greater likelihood that a country will modify or repudiate a contract with a foreign business."
5. Risk of Expropriation of Private Investment
   This variables evaluates the risk "outright confiscation and forced nationalization" of property. Lower ratings "are given to countries where expropriation of private foreign investment is a likely event."

- *Private credit by deposit money banks and other financial institutions to GDP*
  Annual values from 1980-2003. Data from the Levine-Loayza-Beck data set, World Bank. Source data originally from International Financial Statistics. Calculated as:

$$\frac{\dfrac{F_t}{2Pe_t}+\dfrac{F_{t-1}}{2Pe_{t-1}}}{\dfrac{GDP_t}{Pa_t}}$$

Where F is credit by deposit money banks and other financial institutions to the private sector (lines 22d + 42d IFS) Pe is end-of period consumer price index and Pa is the average consumer price index for the year.

- *POLITY2*

  From the Polity IV project characterizing political regime characteristics and transitions 1800-2002. The POLITY2 index is an index created by subtracting two other indexes, DEMOC- AUTOC. The resulting unified polity scale ranges from +10 (strongly democratic) to -10 (strongly autocratic). DEMOC and AUTOC in turn are constructed by combining three other indexes: competitiveness of political participation, openness and competitiveness of executive recruitment and constraints on the chief executive. The basic data is the result of coding based on historical and contemporary sources by teams of coders cross checking their results according to well defined criteria on the different indexes. For detailed information see Marshall and Jaggers (2002).

Income

Gross domestic product at market prices (SNA68) US$, constant 2000 prices (World development Indicators). GDP is income per capita at the time of first availability of the technology, $\min(YearOfAdoption_{ICT})$. Since most technologies will at least initially not be local the GDP is in current US$ without any PPP adjustment. Investment costs and necessary profit levels are supposed not to be dependent on the local cost level.

Education

This is the education index component of the Human Development Index from UNDP. The index measures a country’s relative achievement in both adult literacy and combined primary, secondary and tertiary gross enrolment. First, an index for adult literacy and one for combined gross enrolment are calculated. Then these two indices are combined to create the education index, with two-thirds weight given to adult literacy and one-third weight to combined gross enrolment.

The following is a list of the variables found most significantly correlated with growth in three influential papers, Barro (1991), Barro (1996) and Sala-i-Martin et al. (2000)

Barro (1991)

- Initial human capital
- GDP per capita
- Fertility rates
- Physical investment to GDP
- Government consumption in GDP
- Political stability
- Market distortions

Barro (1996)

- GDP
- Schooling
- Life expectancy
- Inflation
- Improvments in terms of trade
- Political freedom

Sala-i-Martin et al (2000)

Strongly and robustly related

- Level of income
- Fraction of GDP in Mining
- Sachs and Warner Openness
- Fraction of Confucians

Robustly related

- Life expectancy
- Primary schooling enrolment rate
- Sub-Saharan dummies
- Fraction of protestants
- The fraction of primary exports in total exports
- The real exchange rate distortions

Countries in basic list.

Angola	Ecuador	Korea. Rep.	Romania
Argentina	Egypt. Arab Rep.	Madagascar	Senegal
Armenia	El Salvador	Malawi	Singapore
Australia	Ethiopia	Malaysia	South Africa
Austria	Finland	Mali	Spain
Bangladesh	France	Mexico	Sudan
Belarus	Germany	Mongolia	Sweden
Belgium	Ghana	Morocco	Switzerland
Bolivia	Greece	Mozambique	Thailand
Botswana	Guatemala	Namibia	Tunisia
Brazil	Honduras	Netherlands	Turkey
Bulgaria	Hungary	New Zealand	Uganda
Burkina Faso	India	Nicaragua	Ukraine
Cameroon	Indonesia	Nigeria	United Kingdom
Canada	Ireland	Norway	United States
Chile	Israel	Pakistan	Venezuela. RB
China	Italy	Papua New Guinea	Vietnam
Colombia	Japan	Philippines	Zambia
Cote d'Ivoire	Jordan	Poland	Zimbabwe
Czech Republic	Kazakhstan	Portugal	
Denmark	Kenya	Moldova	